Summary of SANEX Extraction Studies for the
Advanced Fuel Cycle Initiative Program

L. K. Felker and D. O. Campbell[1]
Oak Ridge National Laboratory
Nuclear Science and Technology Division

Abstract

The Oak Ridge National Laboratory is participating in several areas of the Advanced Fuel Cycle Initiative Program. One of these areas is the group separation of the actinide (An) and lanthanide (Ln) series elements during the post-irradiation processing of the various types of reactor fuel. The objective of this processing step is to provide a segregated minor actinide fraction for further transmutation and a fission product fraction for disposal as waste. A review of literature on this subject revealed that the current work in the research community is focused on the dithiophosphinic acids and the triazinylpyridines as possible extractants for this group separation. Methods used previously yielded poorer separations and/or relatively intractable wastes. Two of the dithiophosphinic acids have been tested with a high-burnup plutonium target material, and good separation factors (in the range of 10–30) were obtained. Moreover, the distribution coefficients were in the range suitable for practical solvent extraction processing. The results of the extraction testing, the organic-phase stability, and directions for future studies are discussed in the report.

Introduction

In the various chemical processing schemes for irradiated fuels, the objective is to separate the constituents into discrete streams that can then be utilized further or disposed of as waste. One such scheme would separate a uranium fraction for disposal, recycle the plutonium fraction into mixed oxide fuel, recover a minor actinide fraction for further transmutation (perhaps along with other long-lived radioactive constituents), and yield fission product fractions that could be managed for either short-term or long-term disposal. The purpose of this study was to find and develop an effective process for separating the minor actinides from the lanthanide fission products, which is generally recognized as the most difficult separation problem of all. The most successful methods have used ion exchange or solvent extraction from concentrated LiCl solutions or ion exchange chromatography with specific organic complexing agents; both approaches lead to serious waste management problems.

[1] Consultant

The source of the feed for this separation process could range from the high level waste (HLW) from processing of spent light-water-reactor fuel, to a recycle fraction from transmutation processes, or transplutonium element recovery operations from high-burnup targets. It is assumed that the major constituents (i.e., uranium, plutonium, neptunium and some fission and activation products) have been removed in initial processing schemes. The European Commission studies[2] focused on a number of new reagents for accomplishing this An(III)/Ln(III) separation. The study was designed to develop a system that would selectively extract An(III) over Ln(III) from an aqueous nitric acid feed solution while avoiding some of the drawbacks commonly encountered in these types of processes such as precipitation, third-phase formation, difficult pH control, and reagent loss to radiation damage or solubility.

It is important to keep in mind the ultimate waste management issue. Process chemicals are major contributors to the waste generated in the fuel cycle. Some reagents (those consisting of C, H, O, and N) can be oxidized and converted to gaseous products such that they do not contribute to the final waste. However, extractants and ion exchange resins usually contain other elements that do contribute to the waste and, in fact, complicate its management; these include, in particular, phosphorus-based extractants such is tributyl phosphate. Thus, there is a desire to find a useful process using CHON reagents, or at least to minimize other chemicals such as P, S, and inorganic salts in general.

Some of the early work in this area utilized a commercial reagent, CYANEX® 301 {bis-(2,4,4-trimethylpentyl) dithiophosphinic acid}, which showed large separation factors for americium and europium with the carefully purified reagent and in synergistic systems with tributyl phosphate, trioctylphosphine oxide, and other similar compounds. However, the distribution coefficients were usefully large only at low acid concentrations (pH>3), where HLW, for example, could not be treated because it would be unstable.

The European study for accomplishing this separation, Selective Actinides Extraction (SANEX) utilized several classes of reagents as the development progressed. The European work in this area was reviewed[3]. Promising results were noted for two of the SANEX processes in particular, and further study of these systems was proposed. The SANEX-III process utilized a bis-triazinylpyridine compound, and SANEX-IV utilized a dithiophosphinic acid with aromatic substitution instead of aliphatic as in CYANEX® 301. It is noted that the first of these is a CHON reagent, but the second is not since it contains P, S, and perhaps Cl. Both processes showed good An(III)/Ln(III) separation in an acid range up to ~1.0 *M* HNO_3; however, both exhibited problems due to (1) interfering elements that would be present unless additional pretreatment processes are included and (2) precipitation and phase instability under some useful process conditions.

[2] "New partitioning techniques for minor actinides," C. Madic, M. J. Hudson, J. O. Liljenzin, J. P. Glatz, R. Nannicini, A. Facchini, Z. Kolarik, and R. Odoj, European Commission on Nuclear Science and Technology, EUR 19149 EN, 2000

[3] Personal communication, D. O. Campbell to E. D. Collins, December 8, 2001

The structure of the CYANEX® 301 reagent, {bis-(2,4,4-trimethylpentyl) dithiophosphinic acid}, is shown in Figure 1 below.

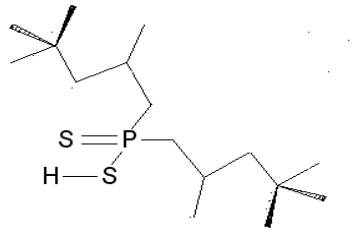


Figure 1. Structure of CYANEX® 301.

The SANEX-IV reagent is a variation of the commercially available CYANEX® 301 compound. In SANEX-IV, an aromatic chlorophenyl group replaces the CYANEX® 301 trimethylpentyl group to increase the acidity of the ligand so that it will extract in a lower pH range. This reagent, bis(chlorophenyl)-dithiophosphinic acid, is not available commercially and must be synthesized. A diphenyldithiophosphinic acid reagent is available commercially and a sample was acquired for initial testing and comparison with the other SANEX extractants. Figure 2 shows the structure for these two compounds. The absence of the chlorine would be advantageous with respect to long-term waste disposition.

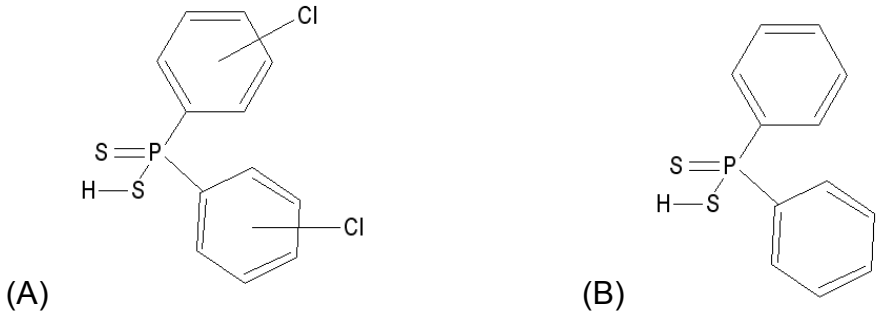


Figure 2. Structure of (A) bis(chlorophenyl)-dithiophosphinic acid and (B) diphenyl-dithiophosphinic acid.

Experimental

Researchers in the Chemical Sciences Division at Oak Ridge National Laboratory reviewed the synthesis of the bis(chlorophenyl)-dithiophosphinic acid compound and subsequently prepared a nominal 100-g batch of the reagent for performing solvent extraction tests. The purity of the initial batch of material was in the 98% range, so a sample was recrystallized and a 45-g batch of >99% purity (^{31}P-NMR determination) was prepared for initial testing. Recovery and further purification of the remaining reagent will follow if needed. Synthesis methods for the Sanex-III extractant have been reviewed, and a preparation of a research quantity is currently underway.

An actinide/fission product feed sample, containing Am/Cm and rare earth fission products, was obtained from the processing of highly irradiated and long-cooled plutonium targets. The Pu targets were first processed to remove and recover Pu, using tributyl phosphate solvent extraction. The raffinate was extracted with di-2-ethylhexyl phosphoric acid to recover the trivalent elements (Am, Cm, and lanthanide fission products) free of most other fission products and impurities. Finally, the trivalents were recovered by oxalate precipitation, and the oxalate was fired to yield an oxide product. A sample of the oxide product was dissolved in nitric acid, and a diluted stock solution was prepared as feed for the extraction testing. The concentrations of the main constituents in the stock solution and the extraction feed dilution are given in Table 1. A second stock solution containing additional cerium, neodymium, and europium (100 g/L total rare earths) was also prepared and added with the radioactive feed to test the distribution/separation at higher rare earth concentrations in extraction test #3.

Table 1. Concentrations of Actinides and Lanthanides in Stock Solution

Constituent	Stock, g/L	Extraction Feed, g/L
Am-241	0.113	0.002
Am-243	0.977	0.019
Total Am	1.09	0.022
Cm-244	0.595	0.012
Rare Earths	~10.0	0.2

The synergist used for these extraction tests was trioctylphosphine oxide, which appeared to give the best results in the European work. Large variations in distribution and separation behavior were observed with different synergists. Diethylbenzene was selected as the diluent since it was readily available and approved for use in the facility. A series of diluents were tested in the European work, and significant differences were noted among the various reagents tested. These systems are complex, and variations in composition of the extractant, synergist, diluent, and (in some cases) modifier, can cause large changes in behavior.

For the first extraction test, two extractants , bis(chlorophenyl)-dithiophosphinic acid and diphenyl-dithiophosphinic acid, were each prepared at 0.5 *M* concentration, with 0.25 *M* trioctylphosphine oxide added as a synergist in a diethylbenzene diluent. The aqueous feed solutions were prepared by dilution of the aqueous stock solution with varying concentrations of nitric acid to yield a series of extraction tests at nominal concentrations of approximately 0.2, 0.4, 0.7, and 1.0 *M* acid for the bis(chlorophenyl)-dithiophosphinic acid extractant and 0.2, 0.35, and 0.5 *M* acid for the diphenyl-dithiophosphinic acid extractant. The samples were equilibrated in centrifuge tubes on a disk rotator for contact times of 4, 10 and 60 min at a phase ratio (O/A) of 0.2 (5 mL aqueous and 1 mL organic) and then centrifuged to obtain clear phases for sampling. Each phase was sampled for gamma counting to determine the distribution coefficients for americium and europium and the corresponding separation factor.

Following promising results from the first test, a second extraction test was made to extend the acid concentration range down to lower values; the nominal acid concentrations were 0.1 *M* and a repeat of the 0.2 *M* acid extraction. The aqueous phase for selected samples was analyzed for acid concentration after the extraction to determine if a significant change had occurred.

In the third series of extraction tests, the rare earth concentration in the feed solution was increased from 0.2 to 6 g/L with the addition of the solution containing cerium, neodymium, and europium. In the European work with these reagents, the increase in the rare earth concentration yielded higher separation factors for the actinides and lanthanides. The initial aqueous-phase nitric acid concentrations were adjusted to 0.1, 0.2, 0.5, 0.7, and 1.0 *M* for the bis(chlorophenyl)-dithiophosphinic acid extractant and 0.1, 0.2, 0.5, and 0.7 *M* for the diphenyl-dithiophosphinic acid extractant. The aqueous and organic phases were sampled after a 15-min equilibration and in duplicate after a 1-h equilibration. The phase ratio was 0.2, the same as in the earlier tests.

Analysis of the aqueous-phase acidity after extraction was performed on selected samples in SANEX test #3 to determine if a significant change in the acid concentration occurred, especially with the samples with higher distributions. The extraction reaction releases equivalent acid from the organic acid extractant to the aqueous phase. The analyzed aqueous-phase acidity was compared with the calculated acidity from the extraction feed preparation, and the measured acidity was usually higher, significantly so for the low acid cases. The acidity was also estimated from the extraction feed preparation corrected for acid exchanged for the extracted metals. Based on all these data, an equilibrium acid concentration was estimated and used in the data plots for the SANEX test #3 data. The nominal and estimated equilibrium acid concentrations are shown in Table 2. In tests #1 and #2 at tracer levels, the acid effect would have been minimal; thus the data is plotted using the initial acid concentrations.

Table 2. Equilibrium Acid Concentrations for Test #3.

Nominal H^+	0.10	0.20	0.50	0.70	1.00
Bis(chlorophenyl)-dithiophosphinic acid:					
Est. Equilibrium H^+	0.15	0.23	0.52	0.71	1.04
Diphenyl-dithiophosphinic acid:					
Est. Equilibrium H^+	0.14	0.23	0.51	0.71	--

A fourth series of extraction tests is in progress, with the rare earth concentration in the feed solution at 6 g/L and the acid adjusted to 0.5, 1.0, 1.5, and 2.0 *M* for the bis(chlorophenyl)-dithiophosphinic acid and the diphenyl-dithiophosphinic acid extractants. These solutions do not contain any added actinide/lanthanide tracer and will be used to monitor the stability of the extractants and the tendency for precipitation at higher acid concentrations during potential extraction and stripping operations.

Results and Discussion

In all the extraction tests, good phase separation was achieved within the first minute after equilibration. Centrifugation yielded clear phases for sampling; however, the aqueous phase did show signs of cloudiness after standing without mixing for approximately 1 h. With additional equilibration and centrifugation, clear phases were again obtained, but the cloudiness then

returned to the aqueous phase after standing. The analysis of the extraction data from tests #1 and #2 showed good distribution for the americium and good separation of the americium from europium in the samples, which is indicative of good actinide/lanthanide separation. The results were essentially the same for contact times between 4 and 60 minutes.

A composite plot of test #1 and #2 distribution coefficients for both extractants is shown in Figure 3 for comparison purposes. The distribution coefficients were calculated using the average of the organic and aqueous sample count rates for the three equilibrations. Obvious discrepancies in the data set were not included in the average. The distribution coefficient data points at 0.2 *M* acid were averaged for the duplicate data sets. The individual plots for each extractant are given in Appendix A, along with the counting data for each sample. The rejected data points were identified in bold. The composite data plot for extraction test #3 with the increased rare earth concentration in the feed solution is shown in Figure 4. Again, good distribution of the americium and good separation of the americium and europium were obtained. The individual extractant data plots and the counting data are included in Appendix A. A comparison of the data in the two plots shows that generally similar distribution is obtained for both extractants. These distribution coefficients are in a good range for solvent extraction process applications as long as the acidity is below about 0.5 *M* for the diphenyl-dithiophosphinic acid and 0.7 *M* for the bis(chlorophenyl)-dithiophosphinic acid.

The composite plot of the separation factors for the tracer level tests and the extraction test with the increased rare earth concentration in the feed solution is shown in Figure 5. The separation factors are the same for a given extractant, both with and without increased rare earth concentration, if the acid is above ~ 0.4 *M.* However, as the acid decreases toward 0.1 *M,* the separation factors decrease substantially for the tracer level test, but remains about constant or increases slightly for the test with increased rare earth concentration. This phenomenon appears to be caused by a low level of a strongly extracting impurity that is more effective at lower acidity. This impurity appears to be complexed by the increased rare earths thus reducing its effect on the lanthanide/actinide separation. The highest separation factors for both extractants appear to be in the 0.4 to 0.5 *M* acid range, but the values are adequate for a good separation process using either extractant, although the bis(chlorophenyl)-dithiophosphinic acid has slightly larger separation factors over a wider range of acidity.

The primary problem appears to be organic-phase stability. After standing for several days without mixing, a precipitate formed in the organic phases at 0.7and 1 *M* with the bis(chlorophenyl)-dithiophosphinic acid and 0.5 and 0.7 *M* acid with the diphenyl-dithiophosphinic acid extractants. This occurred in the first and third series of extraction tests; the second series was at lower acidity. The fourth test was performed to determine if this precipitation was an effect of the acid. In all the tests up to 2.0 *M* acid, clear phases were still evident after 2 or more weeks of contact, in contrast to the observations for tests #1 and #3. This problem with the organic-phase stability was further investigated by submitting a feed sample for mass spectroscopy to determine if any elemental species might be present that could react with the extractants to produce the precipitate. We are currently awaiting the results of this analysis. The cause of the precipitate formation is not known, but it appears to be a complex issue related to the diluent, the modifier, and the exact nature of the dithiophosphinic acid extractants. It might also involve low-concentration impurities that could cause gel formation with the extractant.

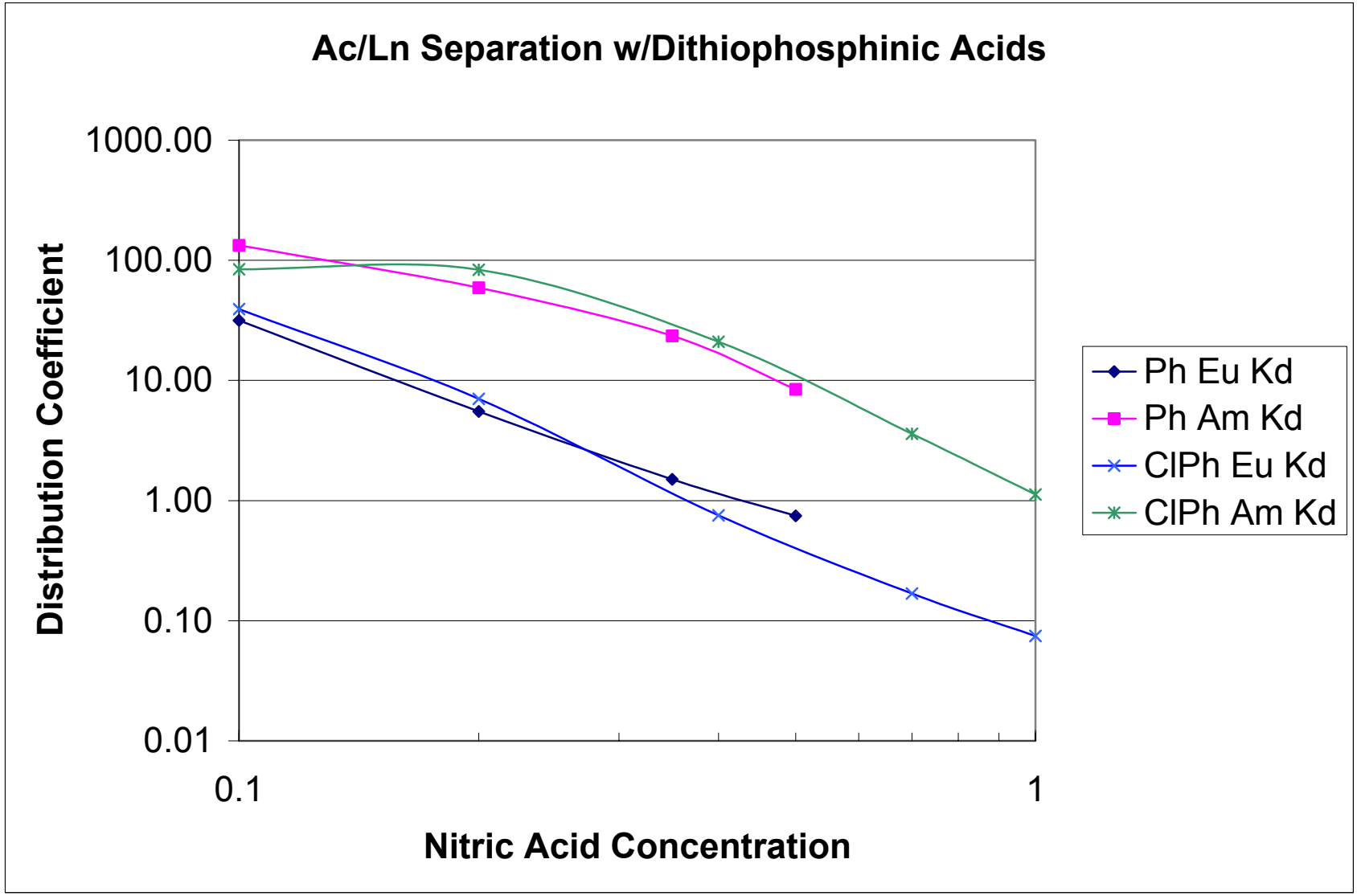


Figure 3. Composite D values for tracer concentrations.

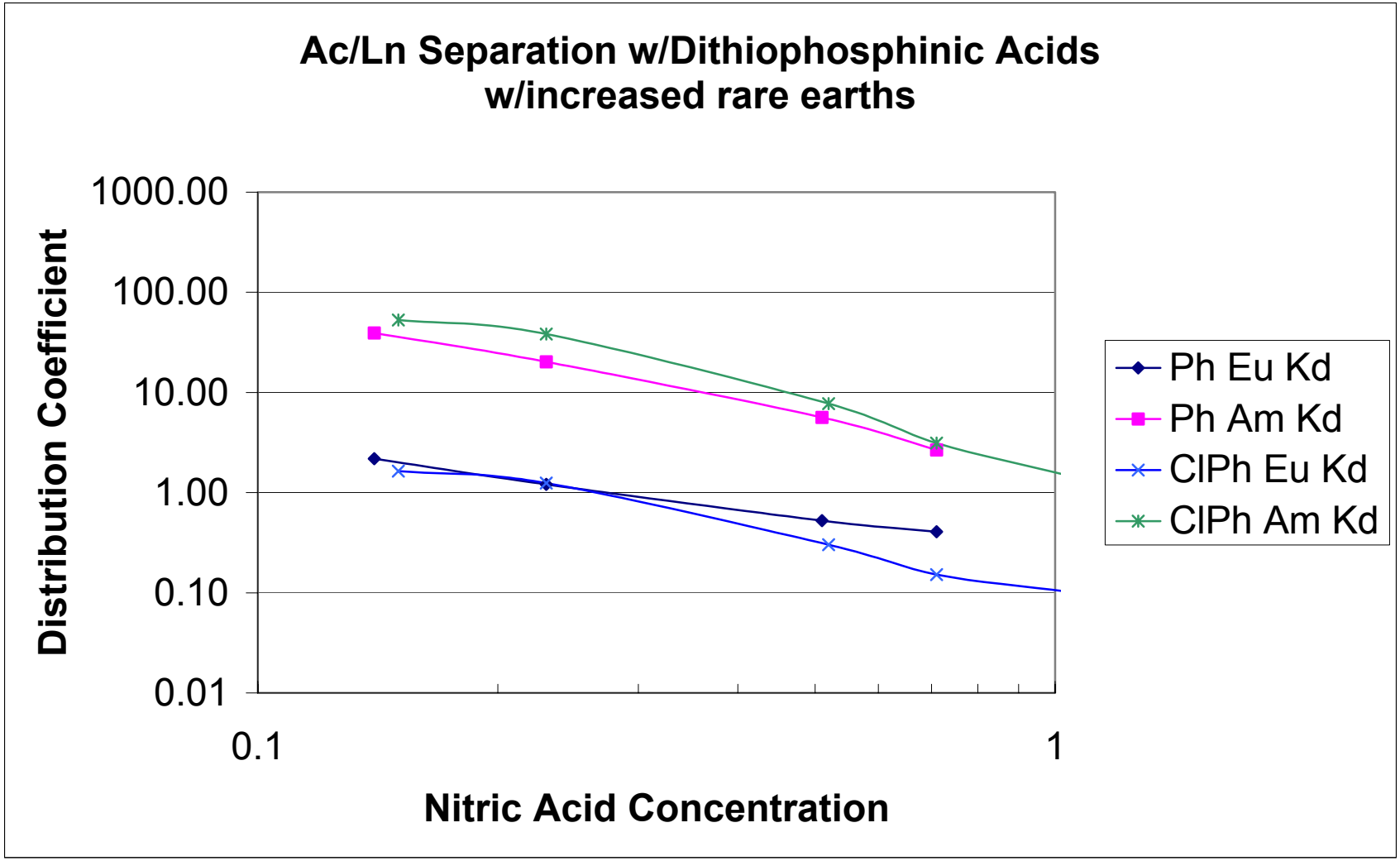


Figure 4. Composite D values with increased rare earth concentration.

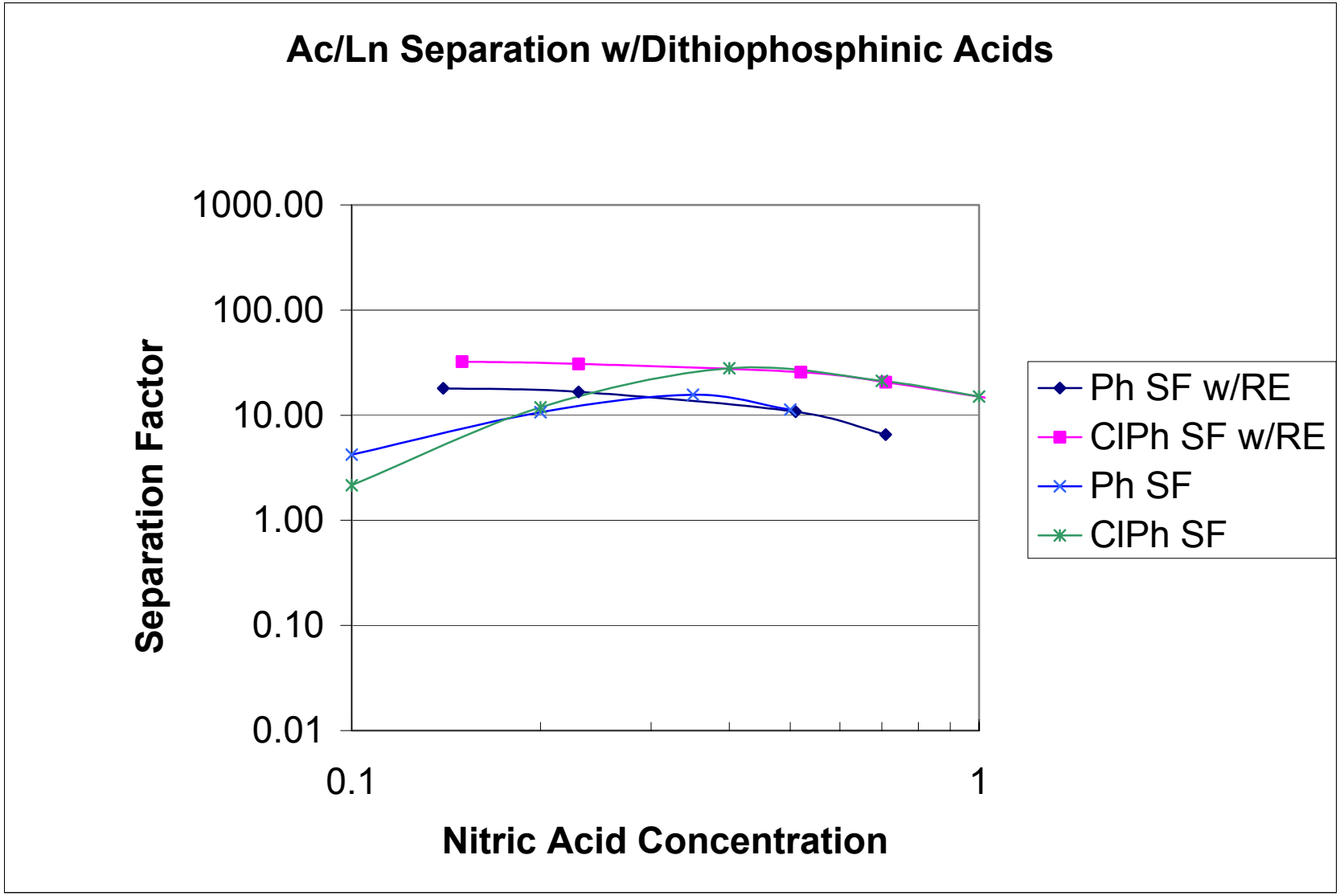


Figure 5. Composite Separation Factor values for tracer and increased rare earth extractions.

The normal approach in this type of solvent extraction process would be to use high acidity to strip the product, but that might result in precipitation. To avoid this problem, it may be necessary to find another means to strip the americium while avoiding high acidity, such as the use of a complexing agent.

During the analysis of the data from SANEX test #3, a bias was observed in much of the data, particularly for the lower-energy gamma emitters. Investigation showed that efficiency factors for the two detectors used for counting were inconsistent in the low-gamma-energy range. A set of standard solutions was prepared and counted under the same conditions as the experimental samples, to determine a correction factor to bring the relative counts for the two detectors into agreement. This empirical correction was applied to all the data sets to remove the bias. It will be necessary to re-standardize the detectors before future samples are counted.

Conclusions and Future Work

Distribution coefficients and separation factors were measured for Eu and Am over a range of nitric acid concentrations from ~0.1 to 1 M, using two different dithiophosphinic acids in synergistic systems with TOPO in DEB. The values obtained were useful for a practical solvent extraction separation process, with extraction of Am and rejection of Eu. There was general agreement with the European work, although we used a different diluent. In the higher ranges of acidity there was precipitation or gel formation in the organic phase in some tests, and this phenomenon is not well understood. This is also in accord with European observations. This suggests that the primary problem with regard to application of the dithiophosphinic acid extractants may be their physical behavior rather than their chemical separation properties. This area will receive more emphasis in future work.

The synthesis of the SANEX-III reagent, a bis-triazinylpyridine compound, is in progress. This reagent also showed promising results in the European work. The structure is shown in Figure 5.

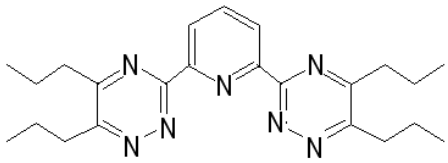


Figure 5. Structure of 2,6-Bis-(5,6-di-*n*-propyl-1,2,4-triazin-3-yl)-pyridine.

A sample of the CYANEX® 301 reagent was obtained from Cytex, Inc., and a portion has been purified for scouting tests with the irradiated target feed solution utilized in this work. This commercially-available reagent requires a low-acid system which may limit its application; but if it is practical, it would be much more economical for larger-scale use. Cytex, Inc., also made available a sample of CYANEX® 923, a trialkyl phosphine oxide mixture, which might serve as a superior synergist in this type of extraction system. Tests of these alternative materials will be conducted. In addition, tests are planned of stripping with aqueous-phase complexants rather than higher nitric acid concentrations.

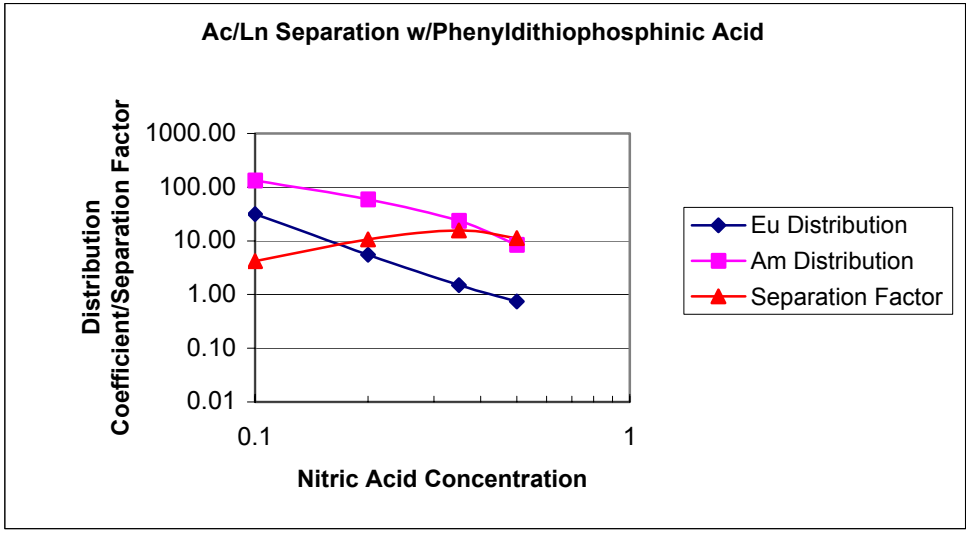
The dithiophosphinic acids and other selected systems will also be tested at higher Am concentrations to establish the effect of the high solvent loading that would be encountered in some projected applications. This will require operation in a facility with greater radiation shielding. Continued testing of these systems will result in a better understanding of the nature of these extractants, their expected behavior, and their limitations.

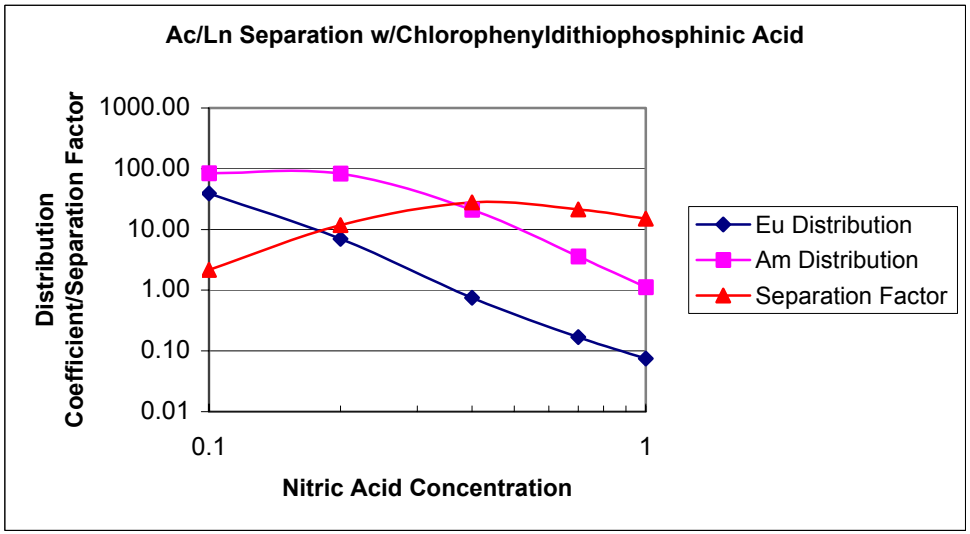
APPENDIX A

Extraction Test #1 & #2 gamma counting data.

Sample	Detector	Eu-154 (Bq/mL)	Corrected	D(Eu)	Eu-155 (Bq/mL)	Corrected	D(Eu)	Am-241 (Bq/mL)	Corrected	D(Am)	Am-243 (Bq/mL)	Corrected	D(Am)	Avg D Eu	Avg D Am	Sep Fac Am/Eu
4R143-Feed	G2	1.07E+06	1.07E+06		2.07E+05	2.07E+05		2.33E+05	2.33E+05		1.52E+05	1.52E+05				
5R15-Feed	G3	8.95E+05	8.82E+05		1.96E+05	1.78E+05		2.02E+05	1.74E+05		1.29E+05	1.16E+05				
Average		9.83E+05	9.76E+05		2.02E+05	1.92E+05		2.18E+05	2.03E+05		1.41E+05	1.34E+05				
4R143-1A1	G2	4.51E+05	4.51E+05		9.31E+04	9.31E+04		1.55E+04	1.55E+04		9.01E+03	9.01E+03				
4R143-1O1	G3	2.76E+06	2.72E+06		6.15E+05	5.57E+05		1.15E+06	9.88E+05		7.82E+05	7.02E+05				
4R143-1A2	G2	4.55E+05	4.55E+05		1.00E+05	1.00E+05		1.67E+04	1.67E+04		9.72E+03	9.72E+03				
4R143-1O2	G3	2.71E+06	2.67E+06		5.96E+05	5.40E+05		1.12E+06	9.62E+05		7.78E+05	6.98E+05				
4R143-1A3	G2	4.46E+05	**4.46E+05**		8.64E+04	**8.64E+04**		1.30E+04	**1.30E+04**		7.16E+03	**7.16E+03**				
4R143-1O3	G3	1.85E+06	**1.82E+06**		4.20E+05	**3.80E+05**		6.92E+05	**5.95E+05**		4.76E+05	**4.27E+05**				
				5.95			**5.68**			**60.56**			**74.77**	**5.81**	**67.66**	**11.64**
4R143-2A1	G2	9.58E+05	9.58E+05		1.95E+05	1.95E+05		4.71E+04	4.71E+04		3.23E+04	3.23E+04				
4R143-2O1	G3	6.37E+05	6.28E+05		1.48E+05	1.34E+05		1.12E+06	9.62E+05		5.25E+05	4.71E+05				
4R143-2A2	G2	7.88E+05	7.88E+05		1.74E+05	1.74E+05		3.61E+04	3.61E+04		2.06E+04	2.06E+04				
4R143-2O2	G3	7.41E+05	7.30E+05		1.65E+05	1.49E+05		1.35E+06	1.16E+06		6.19E+05	5.56E+05				
4R143-2A3	G2	8.69E+05	8.69E+05		1.73E+05	1.73E+05		4.43E+04	4.43E+04		2.62E+04	2.62E+04				
4R143-2O3	G3	6.17E+05	6.08E+05		1.37E+05	1.24E+05		9.93E+05	8.53E+05		5.01E+05	4.50E+05				
				0.75			**0.75**			**23.33**			**18.67**	**0.75**	**21.00**	**27.93**
4R143-3A1	G2	1.04E+06	1.04E+06		2.10E+05	2.10E+05		1.30E+05	1.30E+05		8.64E+04	8.64E+04				
4R143-3O1	G3	3.14E+05	**3.09E+05**		7.39E+04	**6.69E+04**		1.18E+06	**1.01E+06**		5.91E+05	**5.31E+05**				
4R143-3A2	G2	9.61E+05	9.61E+05		2.12E+05	2.12E+05		1.28E+05	1.28E+05		7.47E+04	7.47E+04				
4R143-3O2	G3	1.77E+05	1.74E+05		4.15E+04	3.76E+04		6.37E+05	5.47E+05		3.23E+05	2.90E+05				
4R143-3A3	G2	7.55E+05	**7.55E+05**		1.64E+05	**1.64E+05**		9.88E+04	**9.88E+04**		5.82E+04	**5.82E+04**				
4R143-3O3	G3	1.60E+05	1.58E+05		3.84E+04	3.48E+04		5.43E+05	4.66E+05		2.60E+05	2.33E+05				
				0.17			**0.17**			**3.93**			**3.25**	**0.17**	**3.59**	**21.27**
4R143-4A1	G2	1.02E+06	1.02E+06		2.25E+05	2.25E+05		1.83E+05	1.83E+05		1.19E+05	1.19E+05				
4R143-4O1	G3	7.22E+04	7.11E+04		1.80E+04	1.63E+04		2.61E+05	2.24E+05		1.12E+05	1.01E+05				
4R143-4A2	G2	9.88E+05	9.88E+05		2.15E+05	2.15E+05		1.78E+05	1.78E+05		1.14E+05	1.14E+05				
4R143-4O2	G3	5.36E+05	**5.28E+05**		1.30E+05	**1.18E+05**		2.58E+05	2.22E+05		1.52E+05	1.36E+05				
4R143-4A3	G2	8.40E+05	8.40E+05		1.85E+05	1.85E+05		1.51E+05	1.51E+05		9.64E+04	9.64E+04				
4R143-4O3	G3	6.80E+04	6.70E+04		1.71E+04	1.55E+04		2.31E+05	1.98E+05		9.92E+04	8.90E+04				
				0.07			**0.08**			**1.26**			**0.99**	**0.07**	**1.12**	**15.08**
4R143-5A1	G2	5.19E+05	5.19E+05		1.02E+05	1.02E+05		1.51E+04	1.51E+04		8.82E+03	8.82E+03				
4R143-5O1	G3	3.61E+06	3.56E+06		7.45E+05	6.75E+05		1.58E+06	1.36E+06		1.11E+06	9.96E+05				
4R143-5A2	G2	5.37E+05	5.37E+05		1.05E+05	1.05E+05		2.49E+04	2.49E+04		1.52E+04	1.52E+04				

4R143-5O2	G3	2.38E+06	2.34E+06		5.22E+05	4.73E+05		1.13E+06	9.71E+05		6.66E+05	5.98E+05			
4R143-5A3	G2	5.35E+05	5.35E+05		1.17E+05	1.17E+05		2.14E+04	2.14E+04		1.23E+04	1.23E+04			
4R143-5O3	G3	1.56E+06	**1.54E+06**		3.71E+05	**3.36E+05**		6.43E+05	**5.52E+05**		3.77E+05	**3.38E+05**			
				5.56			**5.31**			**56.88**			**65.84**	**5.44**	**61.36**	**11.28**
4R143-6A1	G2	8.23E+05	8.23E+05		1.59E+05	1.59E+05		4.40E+04	4.40E+04		2.66E+04	2.66E+04			
4R143-6O1	G3	1.05E+06	1.03E+06		2.36E+05	2.14E+05		1.05E+06	9.02E+05		5.39E+05	4.84E+05			
4R143-6A2	G2	7.34E+05	7.34E+05		1.55E+05	1.55E+05		4.28E+04	4.28E+04		2.61E+04	2.61E+04			
4R143-6O2	G3	1.14E+06	1.12E+06		2.55E+05	2.31E+05		1.24E+06	1.07E+06		5.93E+05	5.32E+05			
4R143-6A3	G2	7.01E+05	7.01E+05		1.36E+05	1.36E+05		3.47E+04	3.47E+04		1.92E+04	1.92E+04			
4R143-6O3	G3	1.19E+06	1.17E+06		2.68E+05	2.43E+05		1.23E+06	1.06E+06		6.34E+05	5.69E+05			
				1.47			**1.53**			**24.89**			**22.05**	**1.50**	**23.47**	**15.63**
4R143-7A1	G2	9.06E+05	9.06E+05		2.01E+05	2.01E+05		9.02E+04	9.02E+04		5.49E+04	5.49E+04			
4R143-7O1	G3	6.52E+05	6.42E+05		1.49E+05	1.35E+05		8.59E+05	7.38E+05		4.40E+05	3.95E+05			
4R143-7A2	G2	8.77E+05	8.77E+05		1.93E+05	1.93E+05		8.04E+04	8.04E+04		5.06E+04	5.06E+04			
4R143-7O2	G3	8.63E+05	**8.50E+05**		2.02E+05	**1.83E+05**		1.28E+06	**1.10E+06**		6.11E+05	**5.48E+05**			
4R143-7A3	G2	8.65E+05	8.65E+05		1.88E+05	1.88E+05		8.49E+04	8.49E+04		5.44E+04	5.44E+04			
4R143-7O3	G3	7.11E+05	7.00E+05		1.64E+05	1.49E+05		9.42E+05	8.09E+05		4.80E+05	4.31E+05			
				0.76			**0.73**			**9.08**			**7.75**	**0.75**	**8.42**	**11.29**
5R15-1A1	G3	1.12E+05	1.10E+05		2.41E+04	2.18E+04		1.48E+04	1.27E+04		8.89E+03	7.98E+03			
5R15-1O1	G3	4.16E+06	4.10E+06	**37.14**	9.92E+05	8.99E+05	**41.16**	1.25E+06	1.07E+06	**84.46**	7.47E+05	6.71E+05	**84.03**	**39.15**	**84.24**	**2.15**
5R15-2A1	G2	3.12E+05	3.12E+05		6.40E+04	6.40E+04		1.03E+04	1.03E+04		5.77E+03	5.77E+03			
5R15-2O1	G2	2.64E+06	2.64E+06	**8.46**	5.12E+05	5.12E+05	**8.00**	9.56E+05	9.56E+05	**92.82**	6.12E+05	6.12E+05	**106.07**	**8.23**	**99.44**	**12.08**
5R15-3A1	G3	1.58E+05	1.56E+05		3.39E+04	3.07E+04		1.13E+04	9.71E+03		6.71E+03	6.02E+03			
5R15-3O1	G2	4.82E+06	4.82E+06	**30.96**	9.87E+05	9.87E+05	**32.14**	1.21E+06	1.21E+06	**124.64**	8.51E+05	8.51E+05	**141.28**	**31.55**	**132.96**	**4.21**
5R15-4A1	G3	4.78E+05	4.71E+05		1.03E+05	9.33E+04		2.14E+04	1.84E+04		1.26E+04	1.13E+04			
5R15-4O1	G2	2.44E+06	2.44E+06	**5.18**	5.61E+05	5.61E+05	**6.01**	1.00E+06	1.00E+06	**54.39**	6.67E+05	6.67E+05	**58.97**	**5.60**	**56.68**	**10.13**

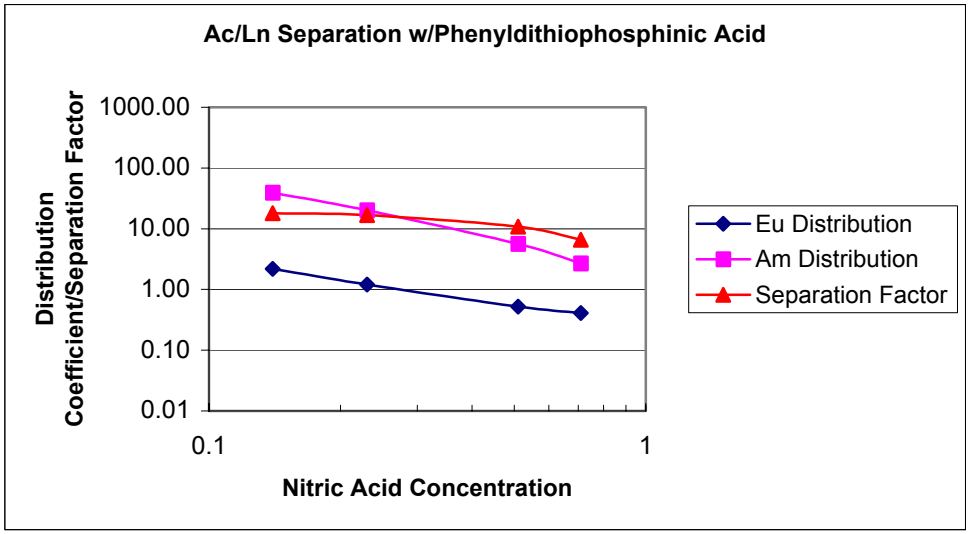

Ac/Ln Separation w/Phenyldithiophosphinic Acid
Distribution Coefficient/Separation Factor
1000.00
100.00
10.00
1.00
0.10
0.01
0.1
1
Nitric Acid Concentration
Eu Distribution
Am Distribution
Separation Factor

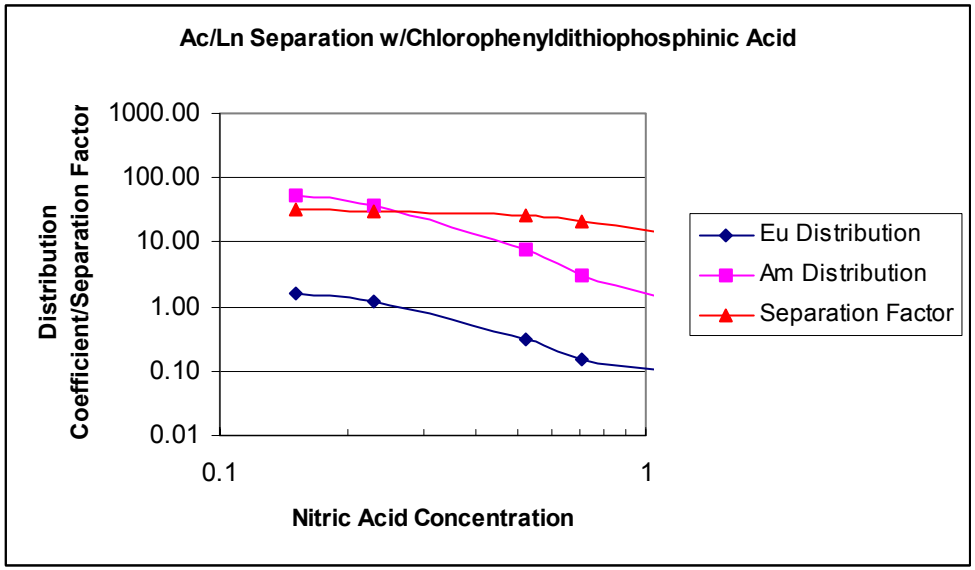

Ac/Ln Separation w/Chlorophenyldithiophosphinic Acid
Distribution Coefficient/Separation Factor
1000.00
100.00
10.00
1.00
0.10
0.01
0.1
1
Nitric Acid Concentration
Eu Distribution
Am Distribution
Separation Factor

Extraction Test #3 gamma counting data

Sample	Detector	Eu-154 (Bq/mL)	Corrected	D(Eu)	Eu-155 (Bq/mL)	Corrected	D(Eu)	Am-241 (Bq/mL)	Corrected	D(Am)	Am-243 (Bq/mL)	Corrected	D(Am)	Avg D Eu	Avg D Am	Sep Fac Am/Eu
5R19-1F	G2	8.57E+05	8.57E+05		1.63E+05	1.63E+05		1.91E+05	1.91E+05		1.22E+05	1.22E+05				
5R19-3F	G2	8.95E+05	8.95E+05		1.96E+05	1.96E+05		2.02E+05	2.02E+05		1.29E+05	1.29E+05				
5R19-5F	G3	8.38E+05	8.26E+05		1.81E+05	1.64E+05		2.14E+05	1.84E+05		1.27E+05	1.14E+05				
5R19-6F	G2	8.55E+05	8.55E+05		1.86E+05	1.86E+05		1.91E+05	1.91E+05		1.22E+05	1.22E+05				
5R19-8F	G3	8.44E+05	8.32E+05		1.80E+05	1.63E+05		2.15E+05	1.85E+05		1.47E+05	1.32E+05				
Average		8.58E+05	8.58E+05		1.81E+05	1.81E+05		2.03E+05	2.03E+05		1.29E+05	1.29E+05				
5R19-1A1	G2	6.18E+05	6.18E+05		1.31E+05	1.31E+05		1.81E+04	1.81E+04		1.04E+04	1.04E+04				
5R19-1O1	G3	1.08E+06	1.07E+06		2.55E+05	2.31E+05		1.17E+06	1.01E+06		6.02E+05	5.41E+05				
5R19-1A2	G2	5.70E+05	5.70E+05		1.24E+05	1.24E+05		1.60E+04	1.60E+04		8.20E+03	8.20E+03				
5R19-1O2	G3	1.03E+06	1.01E+06		2.41E+05	2.18E+05		1.18E+06	1.01E+06		5.74E+05	5.15E+05				
5R19-1A3	G2	6.47E+05	6.47E+05		1.40E+05	1.40E+05		2.20E+04	2.20E+04		1.23E+04	1.23E+04				
5R19-1O3	G3	9.56E+05	9.41E+05		2.16E+05	1.96E+05		1.19E+06	1.02E+06		6.04E+05	5.42E+05				
				1.65			**1.63**			**54.15**			**51.80**	**1.64**	**52.98**	**32.30**
5R19-2A1	G2	8.00E+05	8.00E+05		1.72E+05	1.72E+05		2.58E+04	2.58E+04		1.59E+04	1.59E+04				
5R19-2O1	G3	1.01E+06	9.99E+05		2.32E+05	2.10E+05		1.37E+06	1.18E+06		6.76E+05	6.07E+05				
5R19-2A2	G2	7.72E+05	7.72E+05		1.67E+05	1.67E+05		3.23E+04	3.23E+04		1.79E+04	1.79E+04				
5R19-2O2	G3	9.17E+05	9.03E+05		2.12E+05	1.92E+05		1.25E+06	1.08E+06		6.40E+05	5.75E+05				
5R19-2A3	G2	7.98E+05	7.98E+05		1.72E+05	1.72E+05		3.27E+04	3.27E+04		1.88E+04	1.88E+04				
5R19-2O3	G3	1.06E+06	1.04E+06		2.61E+05	2.36E+05		1.59E+06	1.37E+06		8.39E+05	7.53E+05				
				1.24			**1.25**			**39.87**			**36.84**	**1.25**	**38.35**	**30.79**
5R19-3A1	G2	7.90E+05	7.90E+05		1.73E+05	1.73E+05		8.17E+04	8.17E+04		4.87E+04	4.87E+04				
5R19-3O1	G3	2.37E+05	2.33E+05		5.50E+04	4.98E+04		7.41E+05	6.37E+05		3.85E+05	3.46E+05				
5R19-3A2	G2	7.09E+05	7.09E+05		1.37E+05	1.37E+05		7.08E+04	7.08E+04		4.34E+04	4.34E+04				
5R19-3O2	G3	2.01E+05	1.98E+05		4.97E+04	4.50E+04		6.90E+05	5.93E+05		3.56E+05	3.20E+05				
5R19-3A3	G2	1.58E+06	**1.58E+06**		3.42E+05	**3.42E+05**		1.95E+05	**1.95E+05**		1.20E+05	**1.20E+05**				
5R19-3O3	G3	2.31E+05	2.28E+05		5.51E+04	4.99E+04		7.48E+05	6.43E+05		3.86E+05	3.46E+05				
				0.29			**0.31**			**8.19**			**7.33**	**0.30**	**7.76**	**25.65**
5R19-4A1	G2	9.46E+05	9.46E+05		2.07E+05	2.07E+05		1.41E+05	1.41E+05		8.97E+04	8.97E+04				
5R19-4O1	G3	1.42E+05	1.40E+05		3.56E+04	3.23E+04		5.51E+05	4.73E+05		2.93E+05	2.63E+05				
5R19-4A2	G2	9.08E+05	9.08E+05		1.98E+05	1.98E+05		1.31E+05	1.31E+05		8.30E+04	8.30E+04				
5R19-4O2	G3	1.32E+05	1.30E+05		3.12E+04	2.83E+04		5.01E+05	4.30E+05		2.66E+05	2.39E+05				
5R19-4A3	G2	9.20E+05	9.20E+05		1.72E+05	1.72E+05		1.38E+05	1.38E+05		8.51E+04	8.51E+04				
5R19-4O3	G3	1.35E+05	1.33E+05		3.33E+04	3.02E+04		5.47E+05	4.70E+05		2.78E+05	2.50E+05				
				0.15			**0.16**			**3.35**			**2.91**	**0.15**	**3.13**	**20.68**

5R19-5A1	G2	6.59E+05	6.59E+05	1.32E+05	1.32E+05	1.26E+05	1.26E+05	7.94E+04	7.94E+04				
5R19-5O1	G3	5.58E+04	5.49E+04	1.41E+04	1.28E+04	1.92E+05	1.65E+05	9.54E+04	8.56E+04				
5R19-5A2	G2	5.67E+05	5.67E+05	1.10E+05	1.10E+05	1.11E+05	1.11E+05	6.84E+04	6.84E+04				
5R19-5O2	G3	6.25E+04	6.16E+04	1.54E+04	1.39E+04	2.13E+05	1.83E+05	1.07E+05	9.56E+04				
5R19-5A3	G2	5.89E+05	5.89E+05	1.27E+05	1.27E+05	1.11E+05	1.11E+05	6.80E+04	6.80E+04				
5R19-5O3	G3	6.11E+04	6.02E+04	1.40E+04	1.27E+04	2.68E+05	2.30E+05	1.08E+05	9.68E+04				
				0.10		**0.11**		**1.66**		**1.29**	**0.10**	**1.48**	**14.44**
5R19-6A1	G2	6.31E+05	6.31E+05	1.19E+05	1.19E+05	2.78E+04	2.78E+04	1.68E+04	1.68E+04				
5R19-6O1	G3	1.09E+06	1.07E+06	2.51E+05	2.28E+05	1.10E+06	9.48E+05	5.73E+05	5.14E+05				
5R19-6A2	G2	4.80E+05	4.80E+05	9.67E+04	9.67E+04	2.02E+04	2.02E+04	1.20E+04	1.20E+04				
5R19-6O2	G3	1.09E+06	1.07E+06	2.59E+05	2.35E+05	1.09E+06	9.36E+05	5.90E+05	5.30E+05				
5R19-6A3	G2	5.32E+05	5.32E+05	1.06E+05	1.06E+05	2.72E+04	2.72E+04	1.61E+04	1.61E+04				
5R19-6O3	G3	1.27E+06	1.25E+06	3.10E+05	2.81E+05	1.40E+06	1.20E+06	7.19E+05	6.45E+05				
				2.06		**2.31**		**41.01**		**37.59**	**2.19**	**39.30**	**17.99**
5R19-7A1	G2	8.30E+05	8.30E+05	1.82E+05	1.82E+05	4.78E+04	4.78E+04	2.92E+04	2.92E+04				
5R19-7O1	G3	9.21E+05	9.07E+05	2.07E+05	1.88E+05	1.16E+06	9.97E+05	5.89E+05	5.29E+05				
5R19-7A2	G2	7.98E+05	7.98E+05	1.58E+05	1.58E+05	5.33E+04	5.33E+04	3.18E+04	3.18E+04				
5R19-7O2	G3	1.02E+06	1.00E+06	2.41E+05	2.18E+05	1.25E+06	1.07E+06	6.74E+05	6.05E+05				
5R19-7A3	G2	5.53E+05	**5.53E+05**	1.10E+05	**1.10E+05**	2.79E+04	**2.79E+04**	1.66E+04	**1.66E+04**				
5R19-7O3	G3	1.02E+06	1.00E+06	2.43E+05	2.20E+05	1.35E+06	1.16E+06	6.84E+05	6.14E+05				
				1.19		**1.23**		**21.30**		**19.08**	**1.21**	**20.19**	**16.69**
5R19-8A1	G2	7.63E+05	7.63E+05	1.65E+05	1.65E+05	9.29E+04	9.29E+04	5.89E+04	5.89E+04				
5R19-8O1	G3	4.02E+05	3.96E+05	9.09E+04	8.23E+04	6.15E+05	5.28E+05	3.31E+05	2.97E+05				
5R19-8A2	G2	4.40E+05	**4.40E+05**	9.56E+04	**9.56E+04**	5.47E+04	**5.47E+04**	3.24E+04	**3.24E+04**				
5R19-8O2	G3	4.17E+05	4.10E+05	9.17E+04	8.30E+04	6.44E+05	5.53E+05	3.39E+05	3.04E+05				
5R19-8A3	G2	7.41E+05	7.41E+05	1.59E+05	1.59E+05	9.07E+04	9.07E+04	5.75E+04	5.75E+04				
5R19-8O3	G3	4.00E+05	3.94E+05	9.43E+04	8.54E+04	7.02E+05	6.03E+05	3.36E+05	3.02E+05				
				0.53		**0.52**		**6.12**		**5.17**	**0.52**	**5.65**	**10.77**
5R19-9A1	G2	8.29E+05	8.29E+05	1.81E+05	1.81E+05	1.35E+05	1.35E+05	8.56E+04	8.56E+04				
5R19-9O1	G3	3.86E+05	3.80E+05	8.58E+04	7.77E+04	4.93E+05	4.24E+05	2.63E+05	2.36E+05				
5R19-9A2	G2	8.35E+05	8.35E+05	1.59E+05	1.59E+05	1.36E+05	1.36E+05	8.31E+04	8.31E+04				
5R19-9O2	G3	3.53E+05	3.47E+05	7.85E+04	7.11E+04	4.51E+05	3.87E+05	2.37E+05	2.12E+05				
5R19-9A3	G2	9.59E+05	9.59E+05	2.07E+05	2.07E+05	1.57E+05	1.57E+05	9.99E+04	9.99E+04				
5R19-9O3	G3	3.39E+05	3.34E+05	8.36E+04	7.58E+04	4.88E+05	4.20E+05	2.38E+05	2.14E+05				
				0.40		**0.41**		**2.88**		**2.46**	**0.41**	**2.67**	**6.56**


Ac/Ln Separation w/Phenyldithiophosphinic Acid
Distribution Coefficient/Separation Factor
1000.00
100.00
10.00
1.00
0.10
0.01
0.1
1
Nitric Acid Concentration
Eu Distribution
Am Distribution
Separation Factor


Ac/Ln Separation w/Chlorophenyldithiophosphinic Acid
Distribution Coefficient/Separation Factor
1000.00
100.00
10.00
1.00
0.10
0.01
0.1
1
Nitric Acid Concentration
Eu Distribution
Am Distribution
Separation Factor